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RAINGAGE NETWORK DESIGN USING NEXRAD PRECIPITATION ESTIMATES[1]

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ABSTRACT: A general framework is proposed for using precipitation estimates from NEXRAD weather radars in raingage network design. NEXRAD precipitation products are used to represent space time rainfall fields, which can be sampled by hypothetical raingage networks. A stochastic model is used to simulate gage observations based on the areal average precipitation for radar grid cells. The stochastic model accounts for subgrid variability of precipitation within the cell and gage measurement errors. The approach is ideally suited to raingage network design in regions with strong climatic variations in rainfall where conventional methods are sometimes lacking. A case study example involving the estimation of areal average precipitation for catchments in the Catskill Mountains illustrates the approach. The case study shows how the simulation approach can be used to quantify the effects of gage density, basin size, spatial variation of precipitation, and gage measurement error, on network estimates of areal average precipitation. Although the quality of NEXRAD precipitation products imposes limitations on their use in network design, weather radars can provide valuable information for empirical assessment of raingage network estimation errors. Still, the biggest challenge in quantifying estimation errors is understanding subgrid spatial variability. The results from the case study show that the spatial correlation of precipitation at subgrid scales (4 km and less) is difficult to quantify, especially for short sampling durations. Network estimation errors for hourly precipitation are extremely sensitive to the uncertainty in subgrid spatial variability, although for storm total accumulation, they are much less sensitive.
(KEY TERMS: network design; hydrologic sampling; precipitation measurement; NEXRAD; Catskill Mountains.)

INTRODUCTION

Raingage network design is a problem that has received considerable attention in the hydrologic literature (for a review see Bras and Rodríguez-Iturbe, 1985). An objective of raingage network design is to determine the effects of raingage sampling (both the number of gages and their locations) on the estimation uncertainty of precipitation variables or hydrologic variables computed from precipitation estimates (Bras *et al.*, 1988). This is done using either theoretical models of the rainfall process (Rodríguez-Iturbe and Mejía, 1974a; Peters-Lidard and Wood, 1994) or high resolution rainfall data from dense networks or weather radars (Huff, 1970; Seed and Austin, 1990; Fontaine, 1991).

The use of theoretical models of the rainfall process has certain advantages in raingage network design. For example, Rodríguez-Iturbe and Mejía (1974a) applied an analytical model of rainfall to derive precipitation estimation variance as a function of gage density, area of interest, correlation length scale of the rainfall process, and variance of the rainfall process. Their work considers both long-term and storm event rainfall as well as stratified (uniform) and random sampling designs. Peters-Lidard and Wood (1994) extended this approach to include events with anisotropic, time-dependent correlation structures and hierarchical clustering behavior, using a space-time stochastic model of rainfall. The use of a stochastic rainfall model in this case allowed the investigation of raingage sampling at small space (e.g., a few km) and time (e.g., minutes) scales associated with data collection for hydrologic field experiments.

Still, a limitation of using theoretical rainfall models is that space-time patterns of storm precipitation, including the initiation, growth, and dissipation of storms, are very difficult to represent with stochastic models. Usually these models assume that the statistical characteristics of precipitation do not vary in space (i.e., a stationary random field). However, cli-

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matological variations are usually evident across large regions for precipitation sampled at both short and long time scales. For example, in regions with complex mountainous terrain, orography is known to affect precipitation formation and accumulation patterns.

The use of high resolution rainfall data in raingage network design attempts to mimic space-time patterns of observed precipitation (Huff, 1970). Of course, the data based approach is restricted to locations where high resolution data are available. With the recent deployment of the NEXRAD network of WSR-88D (Weather Surveillance Radar – 1988 Doppler) weather radars (Klazura and Imy, 1993), high resolution data are now being collected across the United States. Although there are known problems associated with NEXRAD radar rainfall estimates (Smith *et al.*, 1996a; Young *et al.*, 1999, 2000), NEXRAD observations still provide very good qualitative information on space-time patterns of precipitation that can be utilized in water resources applications.

In this paper we propose a general approach for use of NEXRAD radar rainfall data in raingage network design. The approach is similar to that of Seed and Austin (1990), which used radar data in Florida and South Africa to examine precipitation errors for gage sampling with hypothetical stratified and random networks. Specifically, radar rainfall data are used to represent the "true" rainfall fields for the region. However, the proposed approach differs in that the mismatch between the point precipitation (measured at a gage) and true areal average precipitation (for each radar grid cell) is considered using a theoretical model to represent the subgrid spatial variability of precipitation and gage measurement errors. As will be seen, the effect of subgrid spatial variability is very important for short sampling durations.

In the following sections, the proposed framework is presented using a case study for a mountainous region in New York. This case study for a region with complex terrain is a challenging application of the approach and demonstrates many issues that need to be considered in raingage network design using NEXRAD precipitation estimates.

SUMMARY AND CONCLUSION

This paper describes a general framework for using NEXRAD precipitation estimates for raingage network design. The approach is illustrated through a case study conducted for six catchments in the Catskill Mountains. Network design experiments quantified the estimation errors in areal average precipitation for the catchments for random gage network alternatives. The mismatch between point (gage) measurement and the areal average precipitation for each radar grid cell was simulated using a model that accounts for spatial variability of precipitation within the grid cell and gage measurement errors.

The case study for the Catskill region shows how the simulation approach can be used to quantify the effects of gage density, basin size, spatial variation of precipitation, and gage measurement error on network estimates of areal average precipitation. Subgrid spatial variability was found to be the most critical factor in error estimation for hourly precipitation. Average errors differed by a 100 percent or more for assumed correlation function models representing low and high subgrid variability. However, for storm total accumulation, average errors differed by around 10 to 25 percent for low and high subgrid variability cases. The high sensitivity for hourly precipitation occurs because (1) the correlation of precipitation in space is much lower, and (2) the shape of the correlation function is more difficult to estimate with available gage observations. A better understanding of small-scale spatial variability of precipitation is needed to improve quantitative estimates of network errors for short sampling durations.

The case study for the Catskill region also demonstrates the challenges in using NEXRAD precipitation estimates in a region with complex mountainous terrain. NEXRAD precipitation estimates suffered from problems due to beam blockage, ground returns, and systematic underestimation. Despite these problems, NEXRAD observations still contain valuable information on space-time patterns of storm rainfall over the region. However, to select the best storms for use in network design, we needed to focus on heavier rainfall events, carefully screen the NEXRAD data, merge estimates from multiple radars, and correct for biases with gage data. Similar efforts may be required in other regions to deal with inherent problems with NEXRAD precipitation estimates.

With conventional approaches to raingage network design, stochastic modeling is often used to simulate space-time patterns for a region. Often these models assume that precipitation fields are stationary, which severely limits their utility in large regions with complex terrain. An advantage of the proposed approach is that it uses the high resolution NEXRAD precipitation estimates to characterize space-time variations over large regions. Stochastic models of the rainfall process are applied only to simulate the mismatch between point and areal precipitation at small-scales (the size of a single radar grid cell). At this scale, the simplifying assumptions needed to model the rainfall process can still be justified. Hence, the proposed approach is ideally suited to applications in regions where significant climatic variations exists.